ILC Positron Source Studies at ANL (DOE Review 2007)

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HEP, ANL

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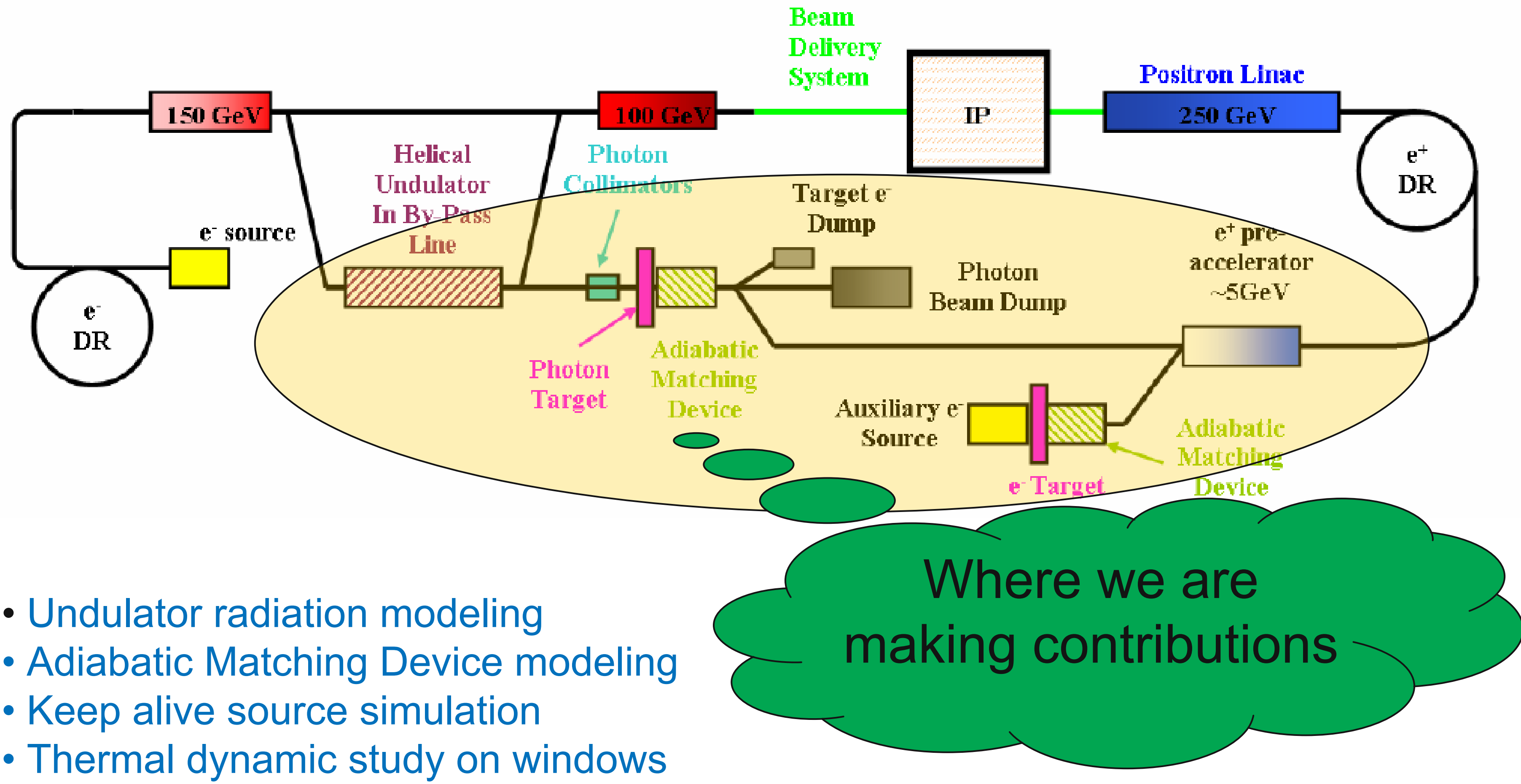
Where we are making contribution



- Undulator radiation modeling
- Adiabatic Matching Device modeling
- Keep alive source simulation
- Thermal dynamic study on windows
- Eddy current simulation
- Laser compton scheme positron production simulation for KEK/CLIC

Outline

- Undulator and e+ yield
- OMD/AMD modeling and designing
- Thermal dynamic of target chamber window
- Energy deposition profile of target
- Collaboration with KEK/CLIC

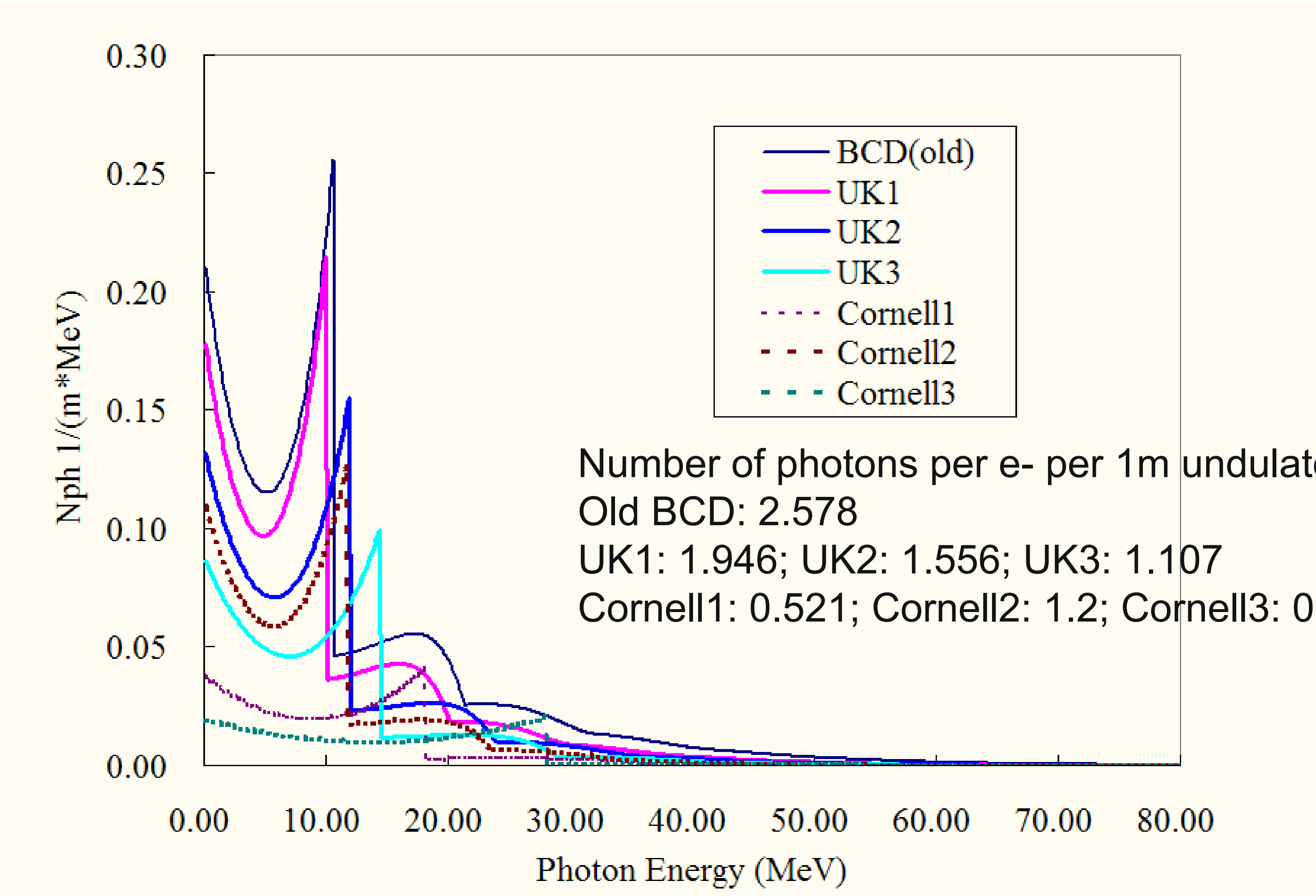
Comparison of positron yield from different undulators

	High K Devices				Low K Devices		
	BCD	**UK I**	**UK II**	**UK III**	**Cornell I**	**Cornell II**	**Cornell III**
Period (mm)	10.0	11.5	11.0	10.5	10.0	12.0	7
K	1.00	0.92	0.79	0.64	0.42	0.72	0.3
Field on Axis (T)	1.07	0.86	0.77	0.65	0.45	0.64	0.46
Beam aperture (mm)	Not Defined	5.85	5.85	5.85	8.00	8.00	
First Harmonic Energy (MeV)	10.7	10.1	12.0	14.4	18.2	11.7	28
Yield(Low Pol, 10m drift)	~2.4	~1.37	~1.12	~0.86	~0.39	~0.75	~0.54
Yield(Low Pol, 500m drift)	~2.13	~1.28	~1.08	~0.83	~0.39	~0.7	~0.54
Yield(Pol)	~1.1	~0.7	~0.66	~0.53	~0.32	~0.49	~0.44

Target: 1.42cm thick Titanium

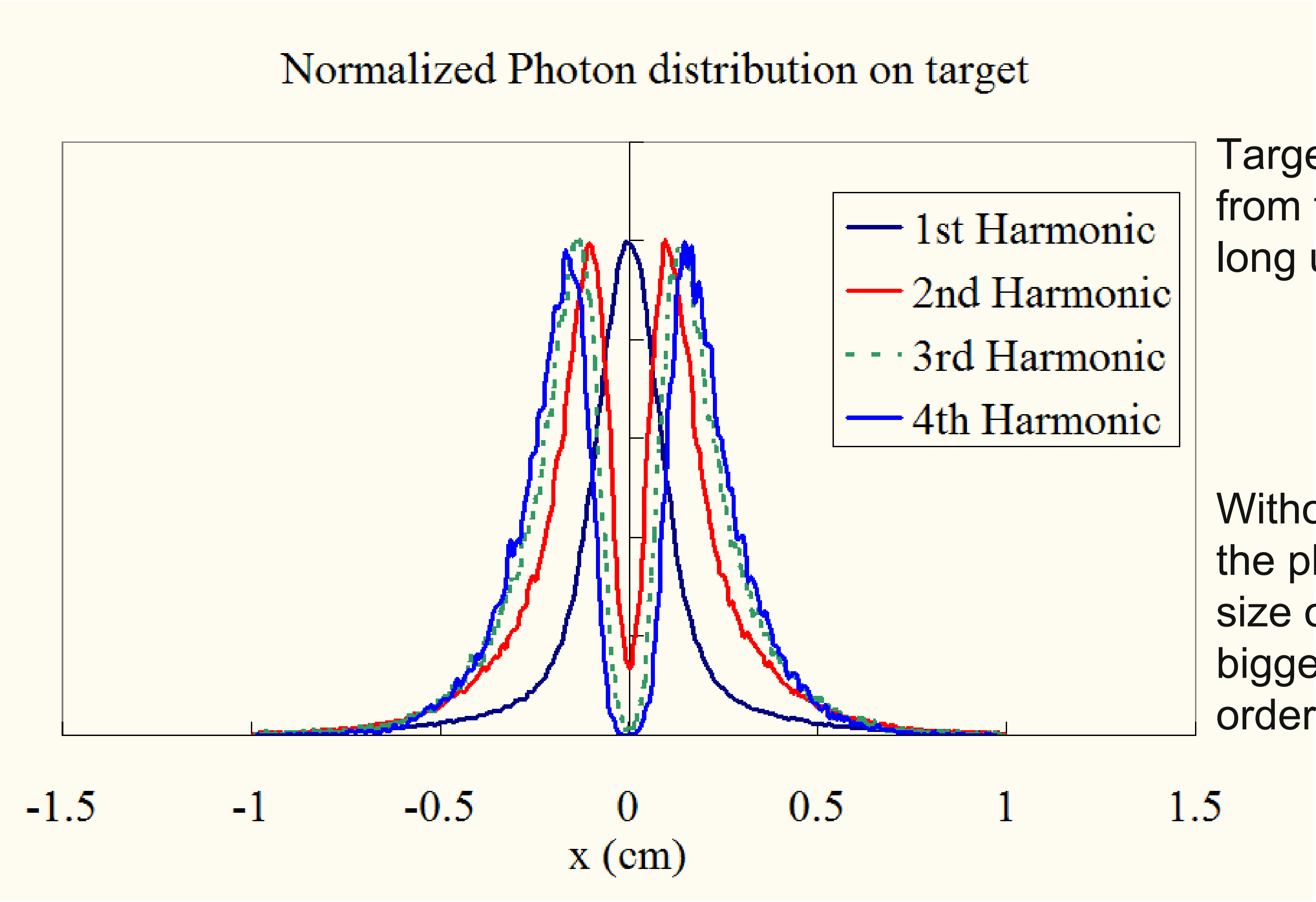
The new baseline

Photon Number Spectrum



Number of photons per e- per 1m undulator:
Old BCD: 2.578
UK1: 1.946; UK2: 1.556; UK3: 1.107
Cornell1: 0.521; Cornell2: 1.2; Cornell3: 0.386

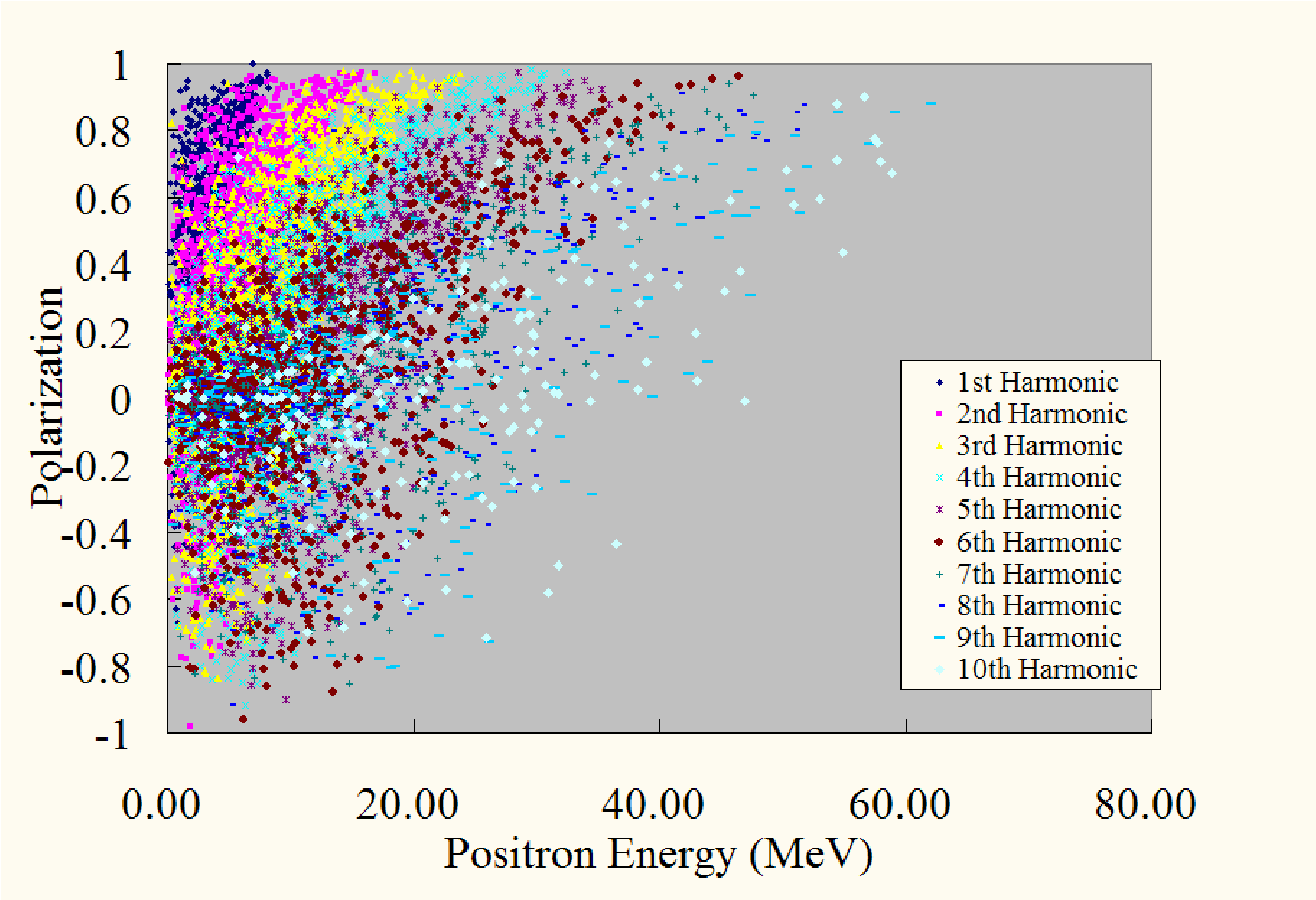
Photon distribution on target, K=0.92,λu=1.15cm, No collimator



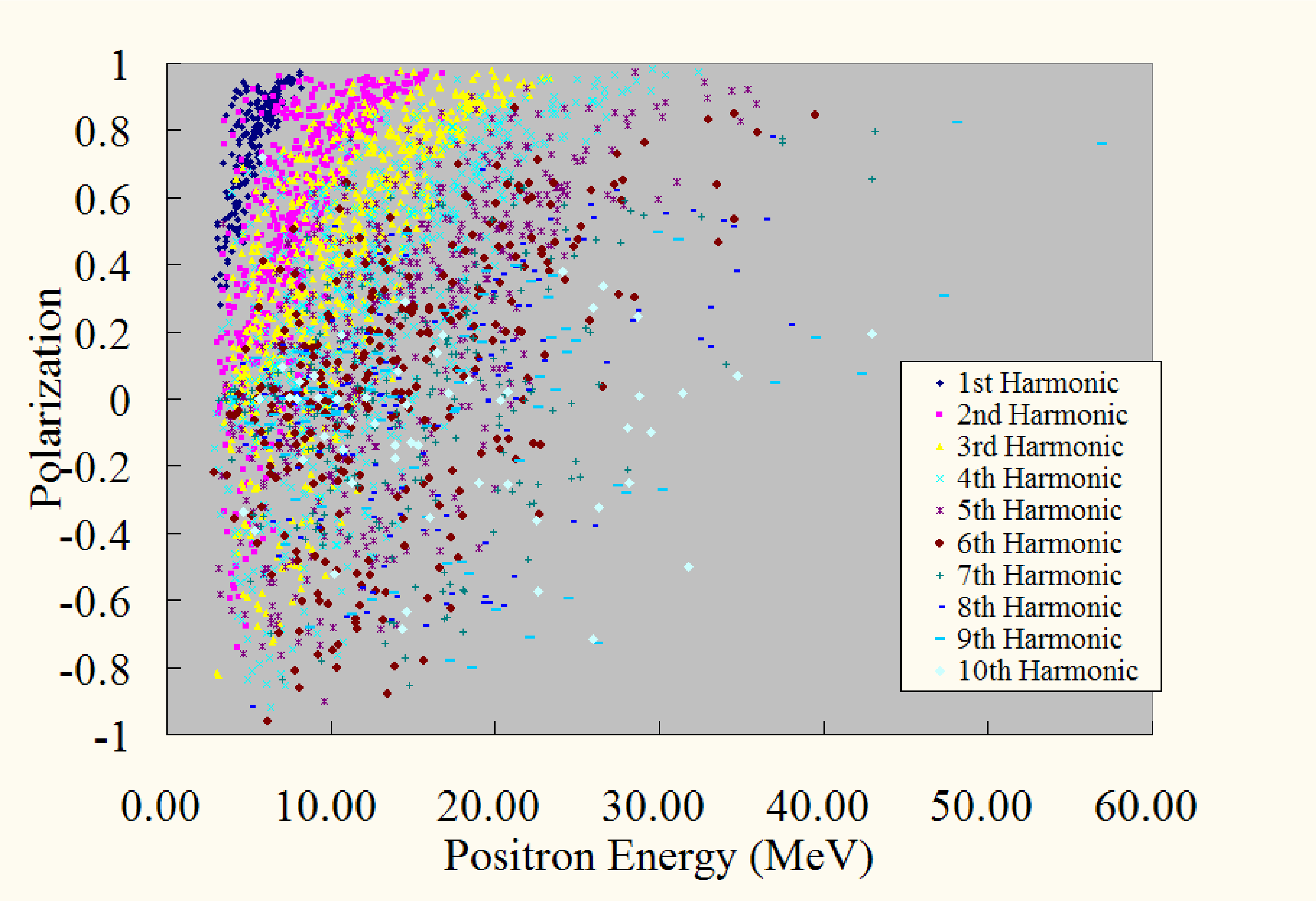
Target is 500m away from the end of 100m long undulator.

Without collimator, the photon spot size on target is bigger due to high order harmonics

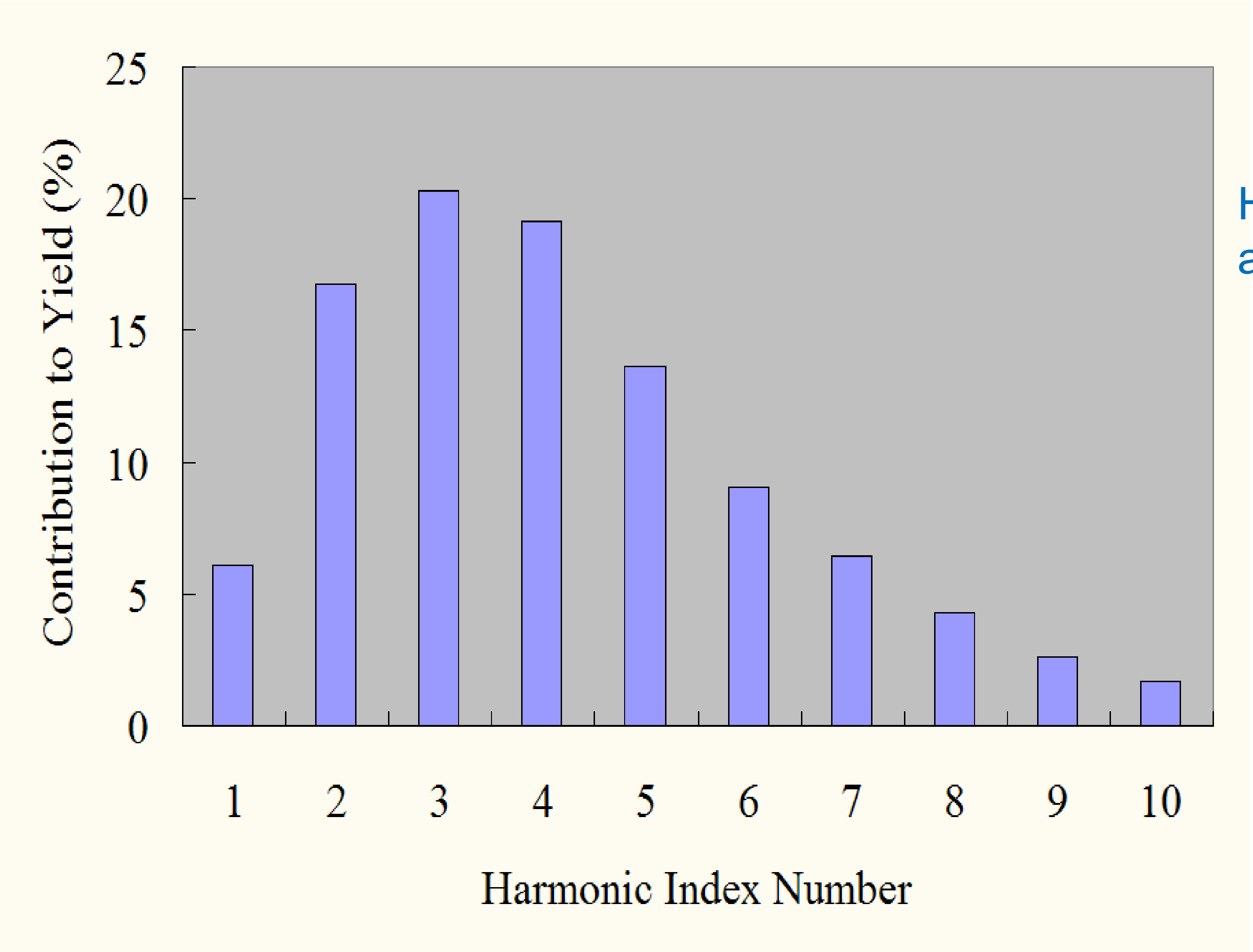
Initial Polarization of Positron beam at Target exit(K=0.92 λu=1.15)



Initial Pol. Vs Energy of Captured Positron Beam



Yield contribution from different harmonics – new baseline undulator, without collimator

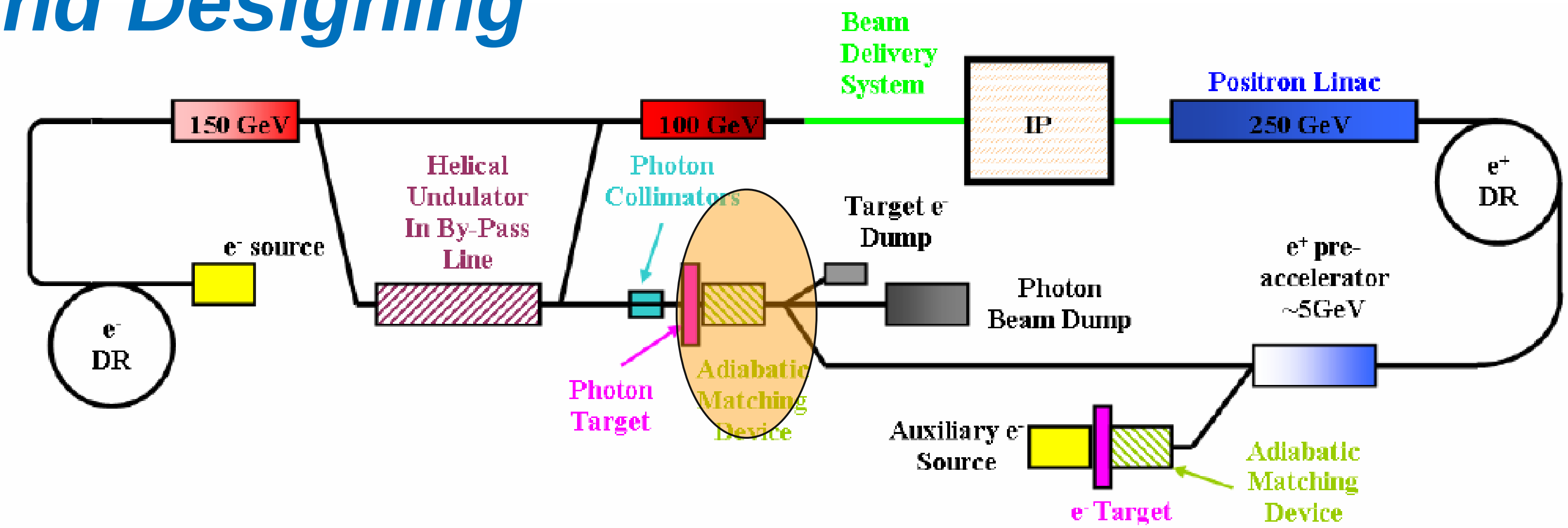


High order harmonics are important

On going and future plans

- Quarter-wave transformer capture studies: how well does this work? Essentially want zero field on target
- Energy deposition calculations for RAL material optimization: start with 5-D acceptance cut to estimate yield and feedback into production calculation to determine incident beam power
- Undulator→Target separation (yield versus spot size); also undulator→dump distance (how much drift is required to permit a window?)

Adiabatic Matching Device Modeling and Designing



To optimize the e+ capture, an AMD field of 5T on surface of target and decrease adiabatically down to 0.25T is required.

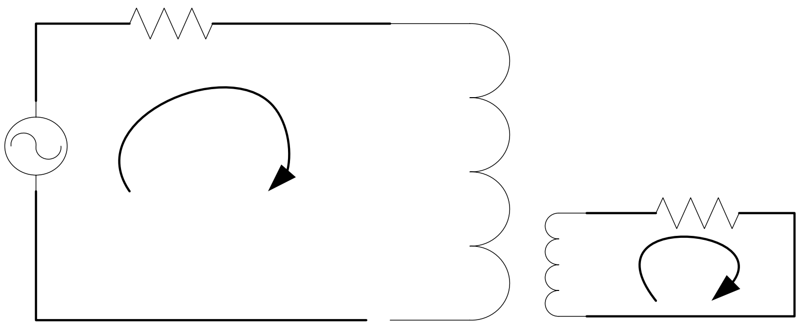
To achieve this high field on the target, one option is to use flux concentrator

Introduction of flux concentrator

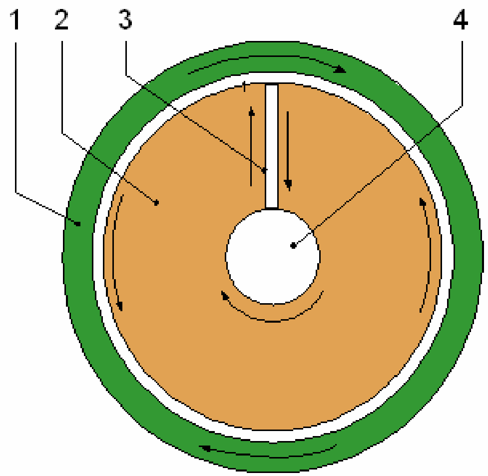
- Work as a pulsed transformer.

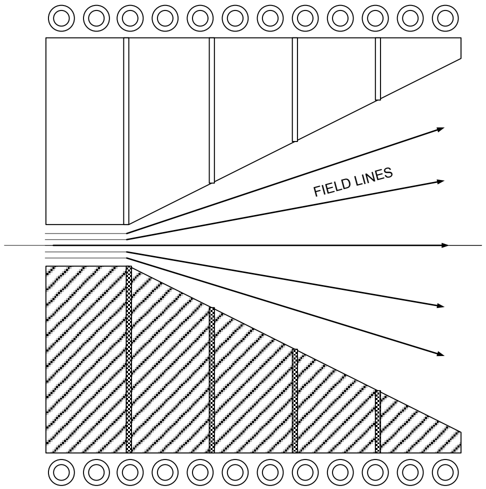
- The induced current generated by the primary coil tends to shift the primary coil flux into the smaller vacuum region inside the central bore and relieves the magnetic pressure on the primary coil.

Simple transformer model which can provide qualitative understanding



1: primary winding,
2: core,
3: radial slot,
4: bore.



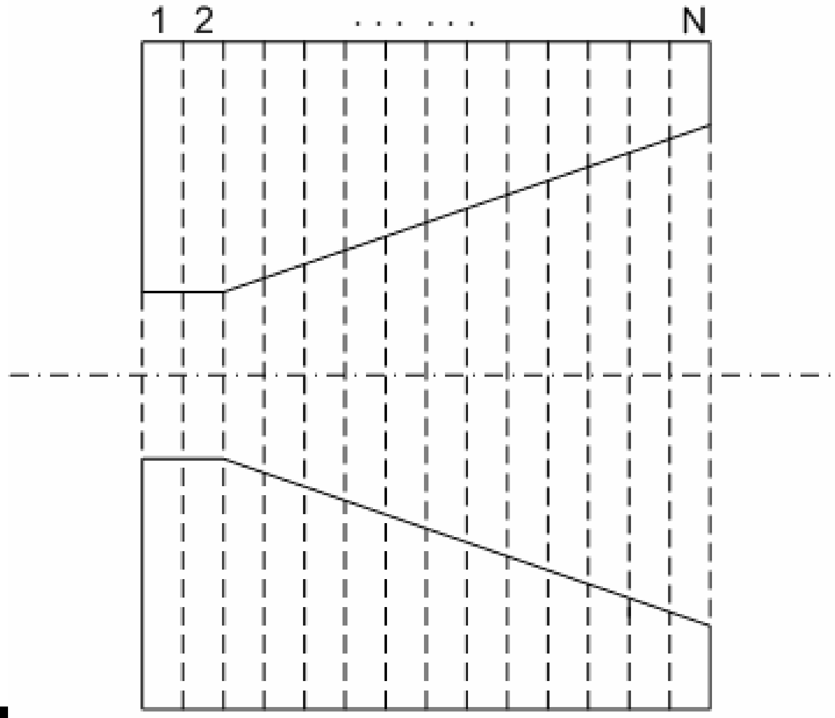


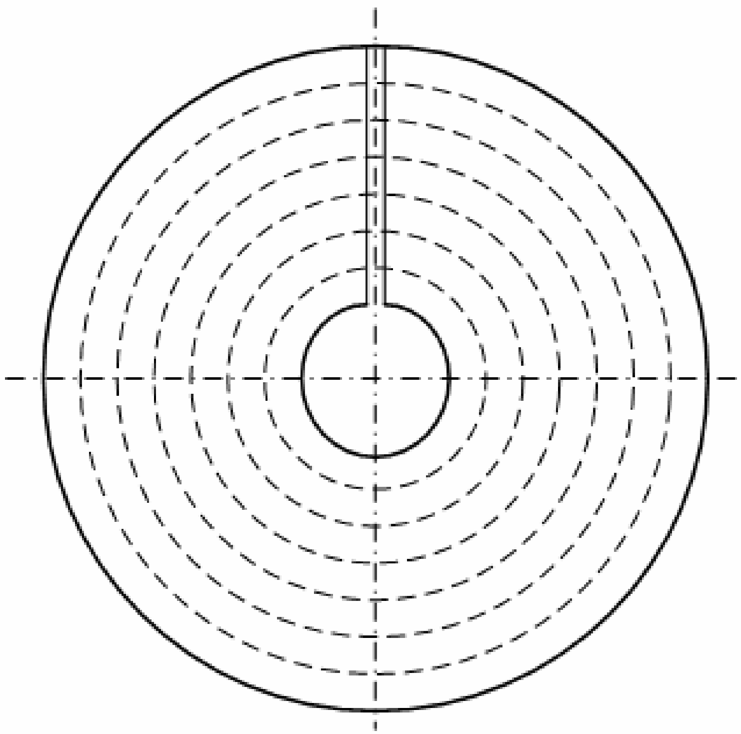
Cross-sectional and side view of a general flux concentrator.

Circuit model of flux concentrator , Geometric "meshing"

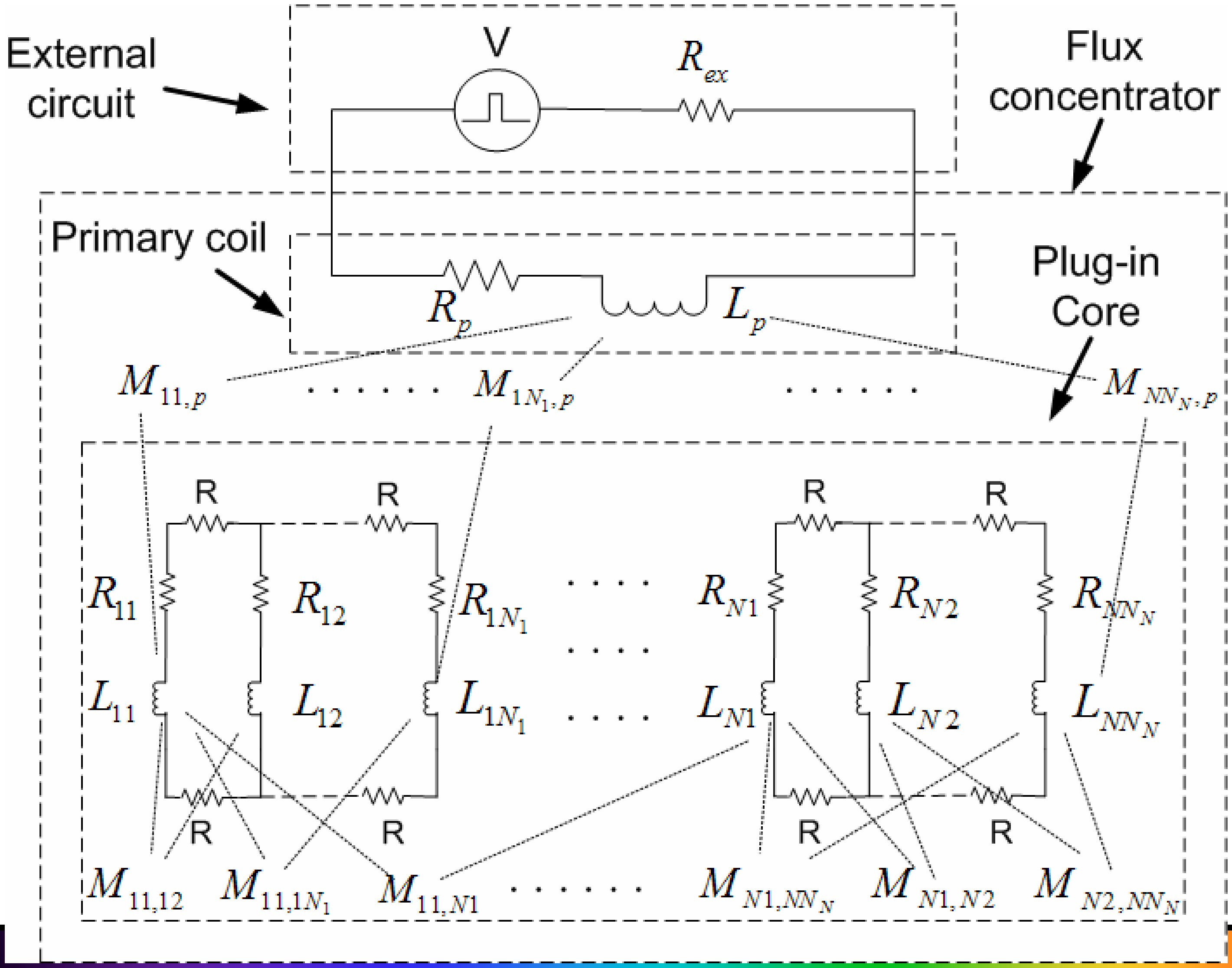
First dividing flux concentrator into thin disks along the axial direction, followed by subdividing each disk into homocentric rings These rings are interconnected at the slot end.

Each concentrating ring is modeled as a resistor and a inductor, and interconnection at slot is modeled as resistors.





Circuit model of flux concentrator
Equivalent circuit



Circuit model of flux concentrator

Circuit equations setup

Circuit equation for the primary loop:

$$v = R_{ex} i_p + (R_p + j\omega L_p) i_p + \sum_{i=1}^{N} \sum_{j=1}^{N_i} j\omega M_{ij,p} i_{ij}$$

For the circuit loop formed by ring (i, j), ring (i, j+1):

$$j\omega M_{ij,p} i_p + (R_{ij} + j\omega L_{ij}) i_{ij} + \sum_{m1=1}^{N} \sum_{k1=1}^{N_{m1}} j\omega M_{ij,m1k_1} i_{m1k1} \delta_{m1k1} + 2R \sum_{k=1}^{j} i_{ik}$$

$$- j\omega M_{i(j+1),p} i_p - (R_{i(j+1)} + j\omega L_{i(j+1)}) i_{i(j+1)} - \sum_{m2=1}^{N} \sum_{k2=1}^{N_{m2}} j\omega M_{i(j+1),m2k2} i_{m2k2} \delta_{m2k2} = 0$$

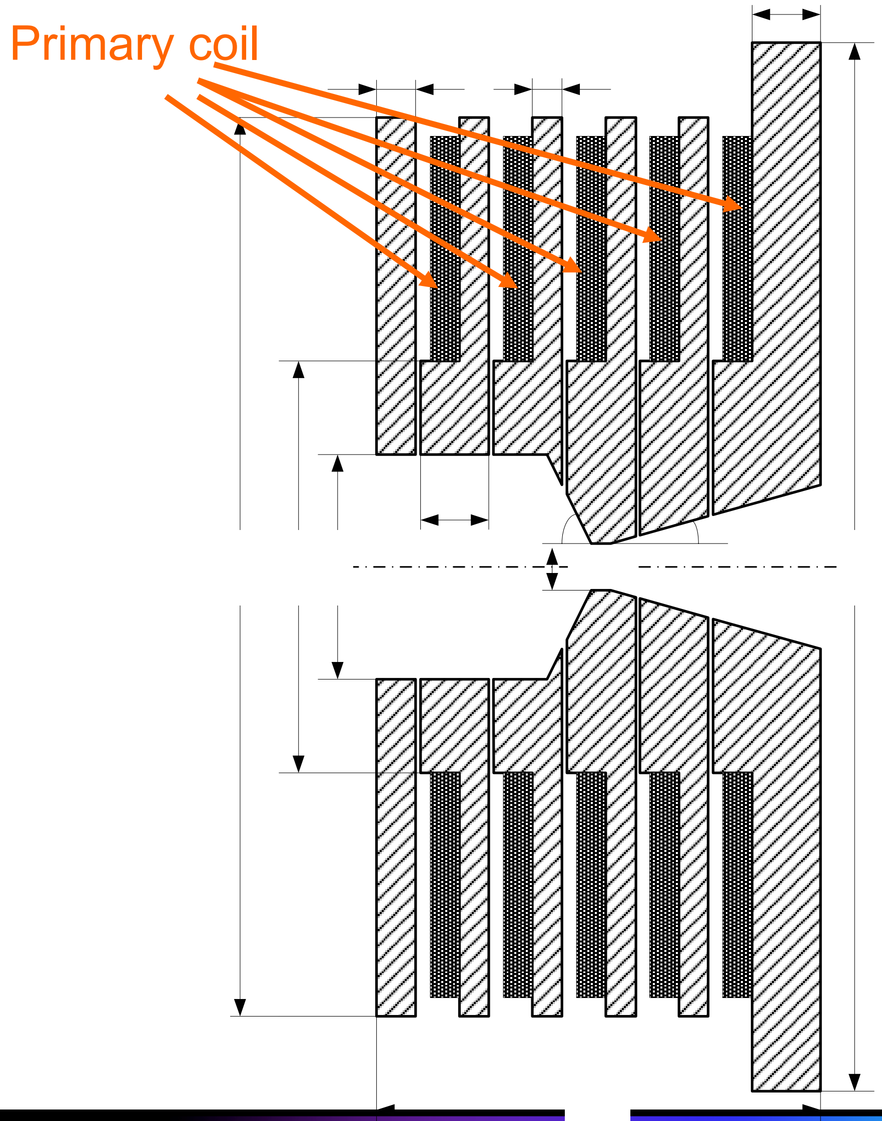
Total currents for each disk:

$$\sum_{j=1}^{N_i} i_{ij} = 0$$

The coupled circuit system with matrix format:

$$Z \times I = V$$

Modeling of **Brechna's** *flux concentrator --Geometry structure*



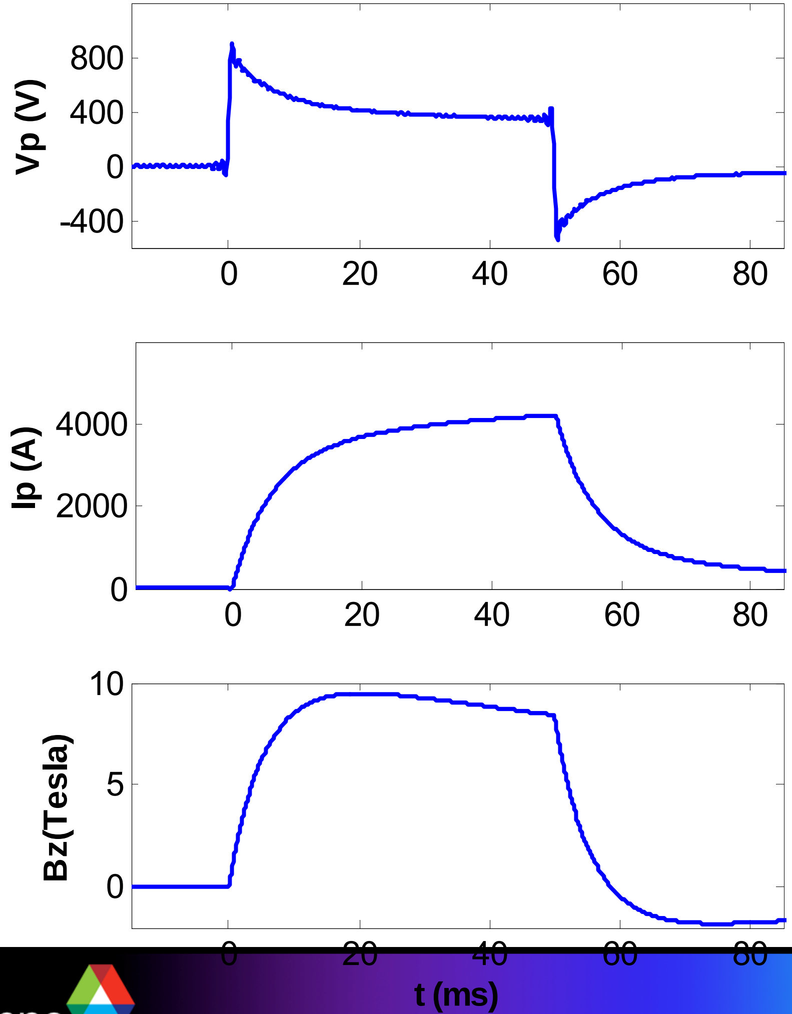
This structure of flux concentrator is from Brechna's paper. We will calculate its transient response and on-axis field profile using our equivalent circuit model.

H. Brechna, D. A. Hill and B. M. Bally, "150 kOe Liquid Nitrogen Cooled Flux-Concentrator Magnet", Rev. Sci. Instr., 36 1529, 1965.

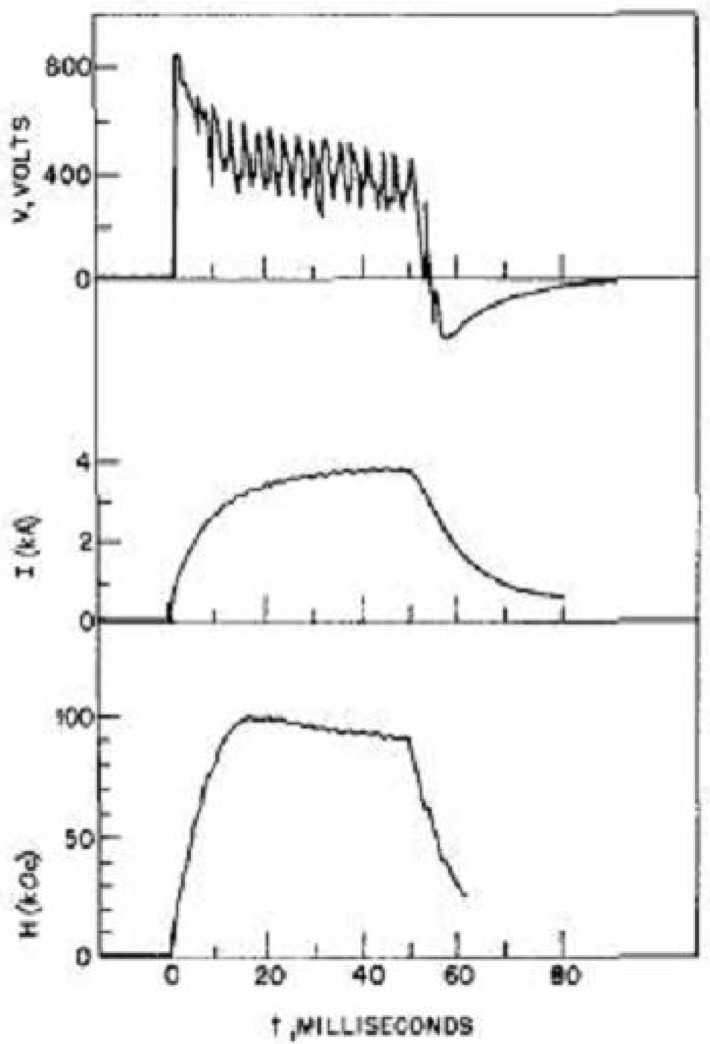
Modeling of **Brechna's** *flux concentrator* *--Comparison between modeling result and published measurement results*

Results from circuit model

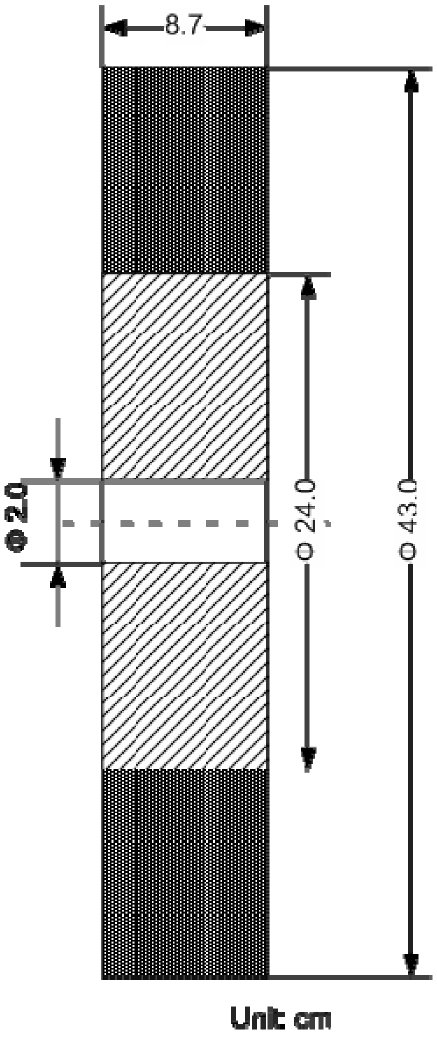
(Source R =0.12 Ω)

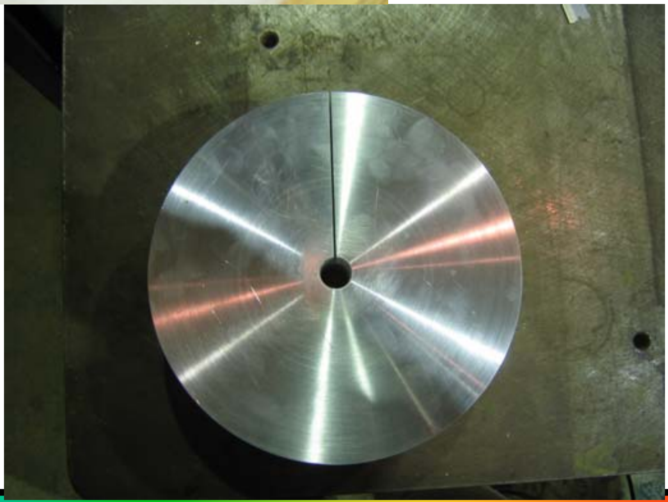


Measurement results



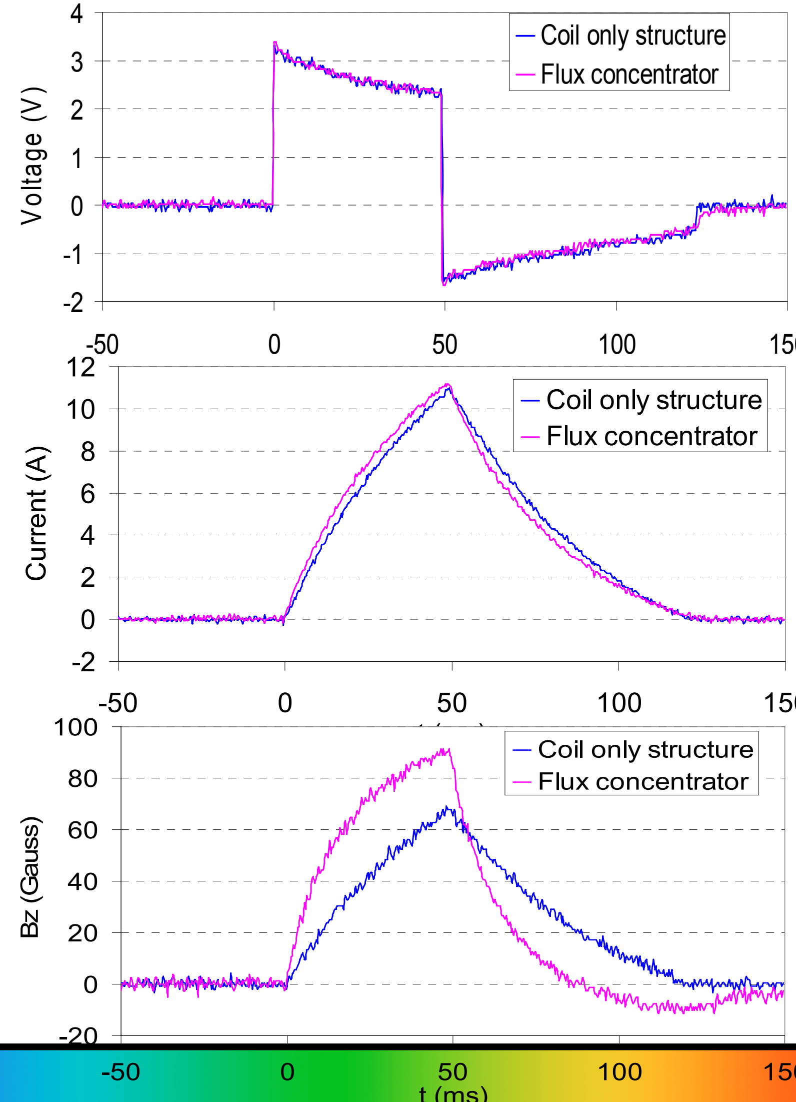
Prototype Flux Concentrator





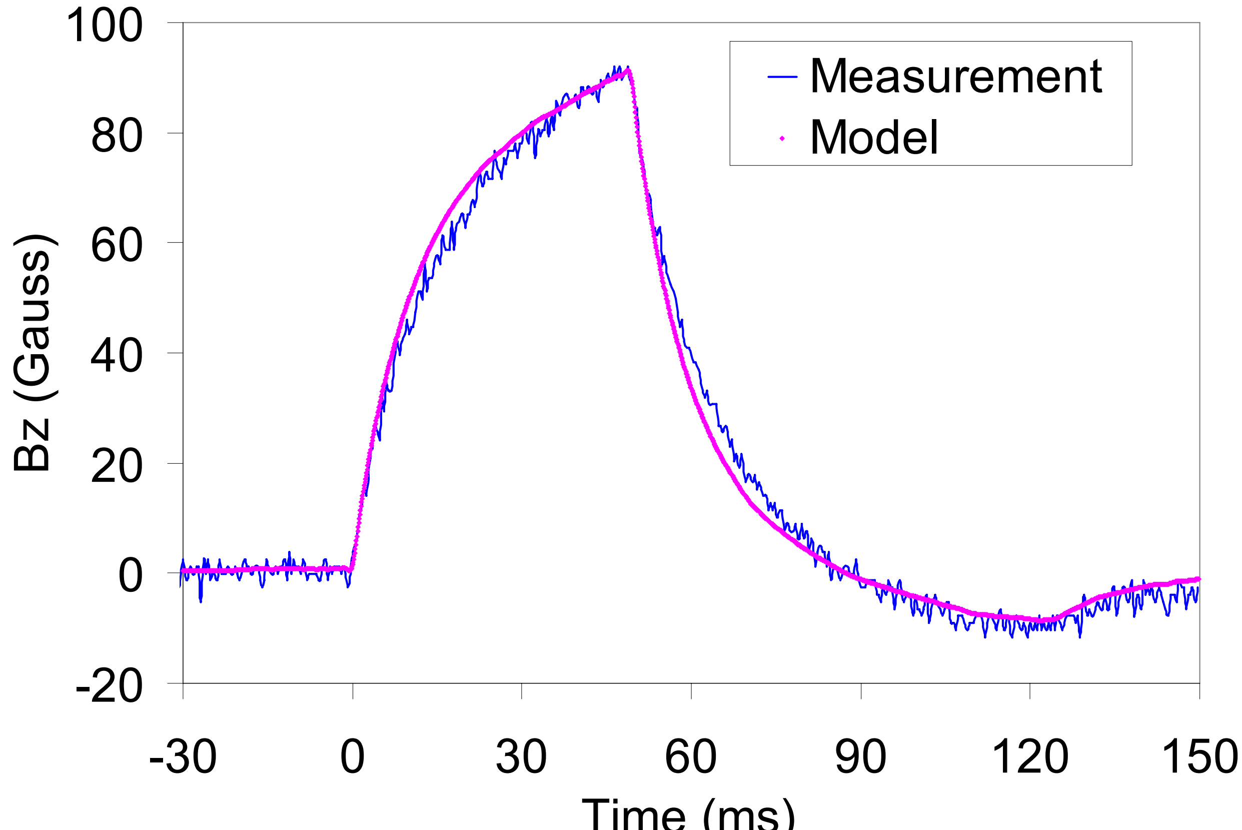
Measurement at room temperature

- Two configurations, one is coil only structure, and another is flux concentrator.
- For both configurations we measured the transient responses of the voltage at the coil terminals, the current flowing through the coil, and the magnetic field at the central axis of the coil assembly.
- Compared to coil only structure, magnetic field at the peak increases 30% for flux concentrator.



Comparison of Measured and Modeling results of transient magnetic field

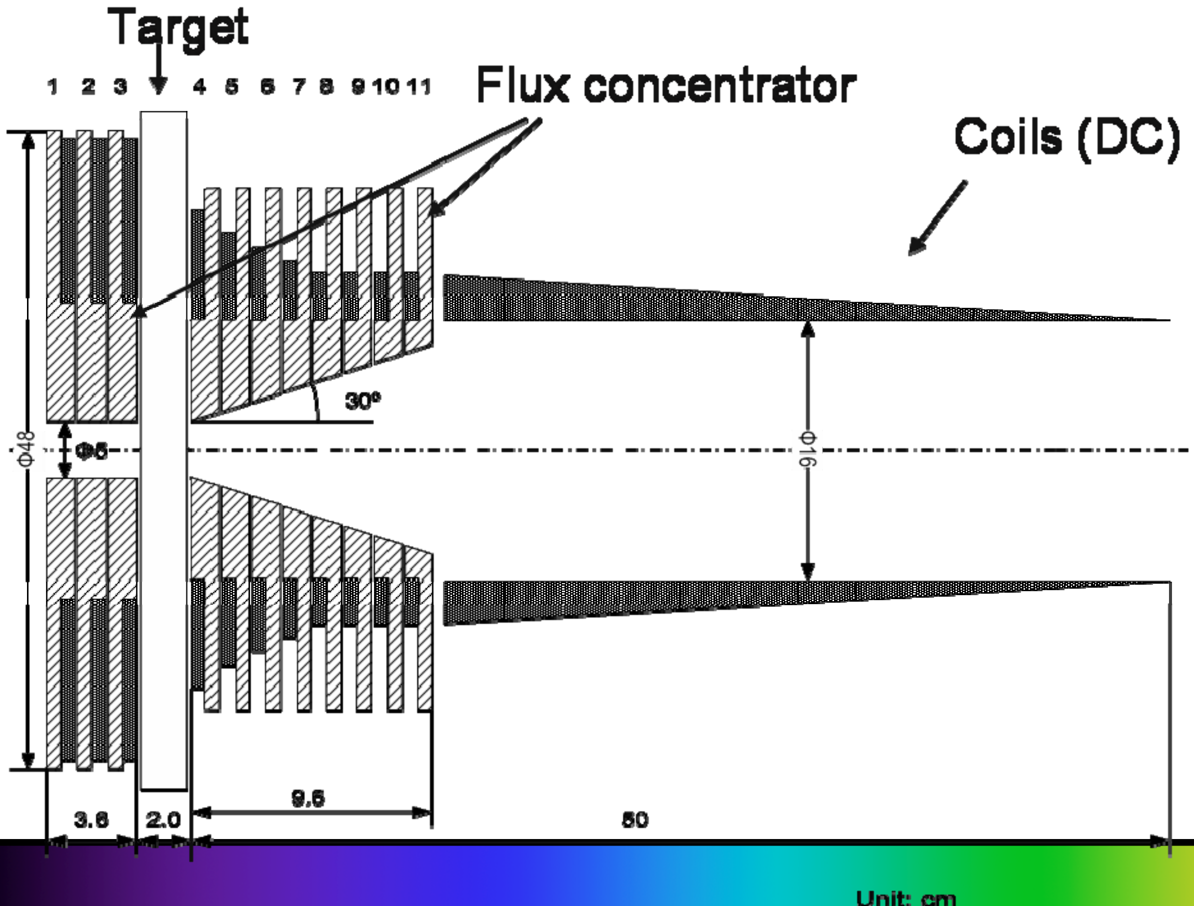
With the same dimensions and material properties of the prototype structure, the transient magnetic field is calculated using the circuit model. A very good agreement is achieved.



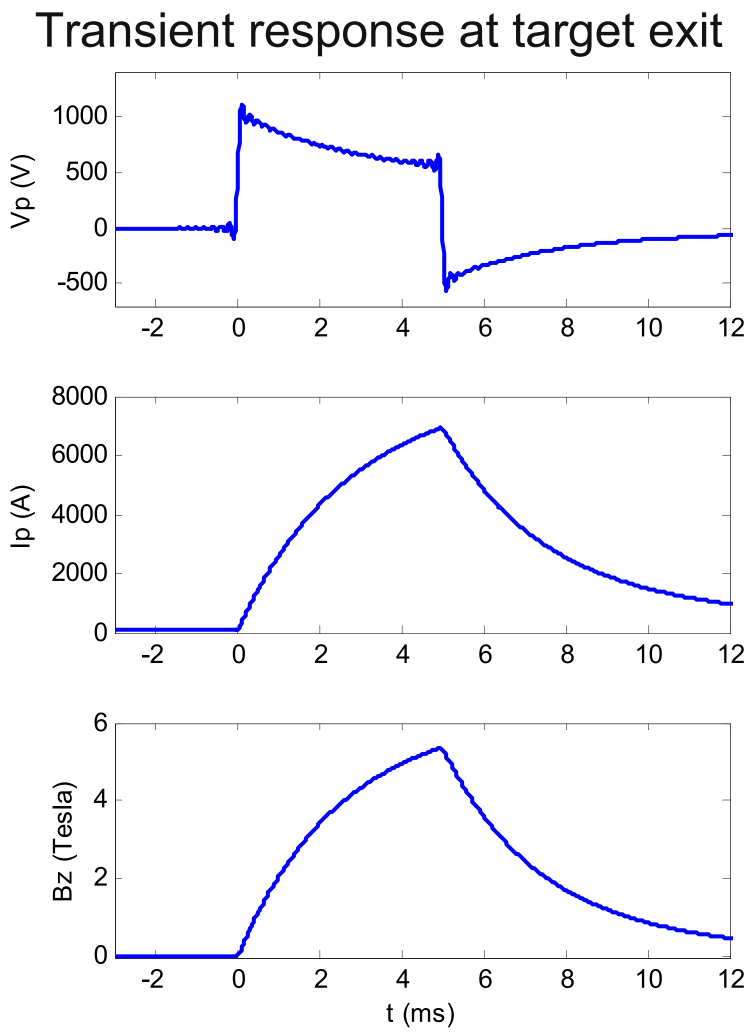
Schematic of Our AMD Design

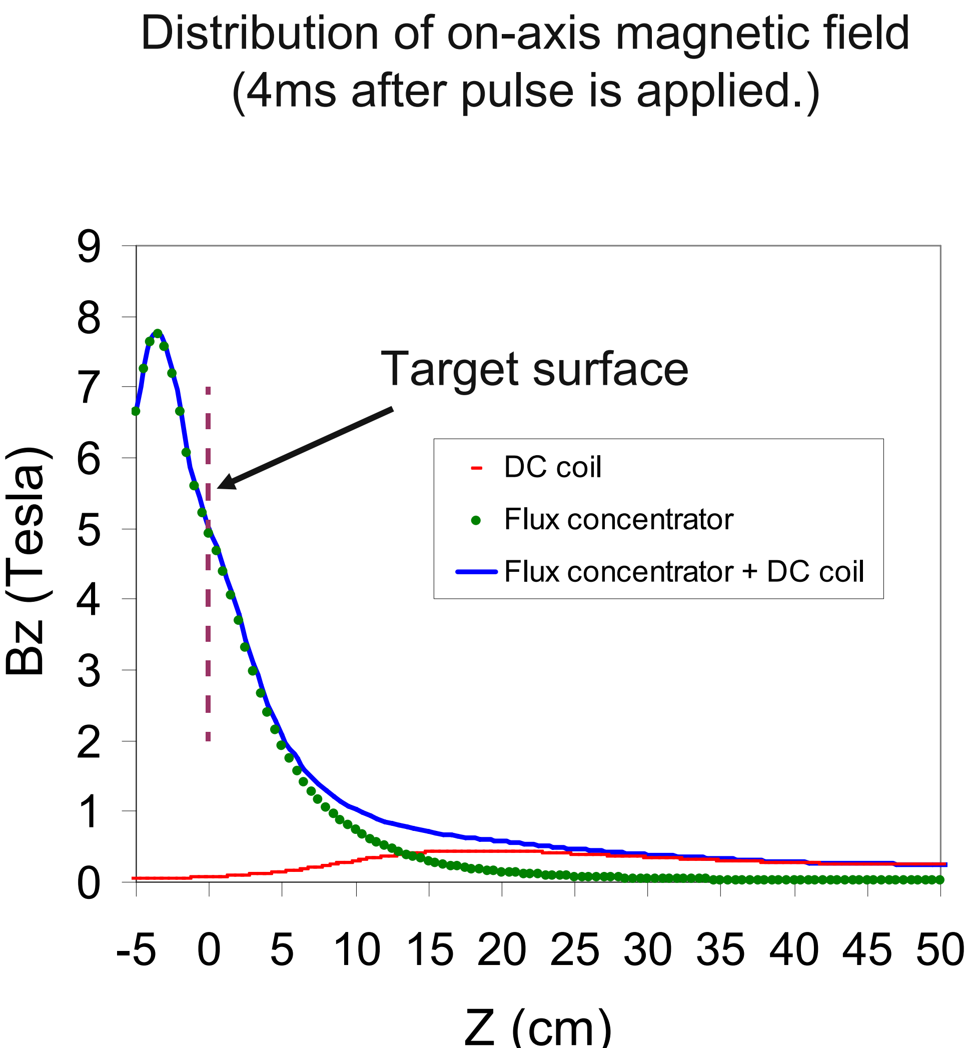
Design requirements:

- Peak on-axis magnetic field at target exit > 5 Tesla,
- Pulse width = 5ms,
- Pulse repetition rate = 5 Hz.



Transient response and field profile





Parameters of the Designed OMD

Parameters of flux concentrator

Work mode	pulse
Operation Temperature	78ºK
Pulse width	5 ms
Repetition rate	5 Hz
Number of turns of primary coil	105
Peak power input to magnet	5.1 MW
Average power input	113 KW
Peak current	7000 A
Magnetic field at target exit	5 Tesla
Time constant of current in primary coil	3 ms
Wire size of primary coil	0.475×0.381 cm²

Parameters of DC coil

Work mode	DC
Operation Temperature	293ºK
Power input	81 KW
Current	926 A
Total Number of turns	135
Wire size of coil	0.475×0.381 cm²

- We developed a circuit model based on frequency domain analysis to calculate transient response of a flux concentrator and its field profile.

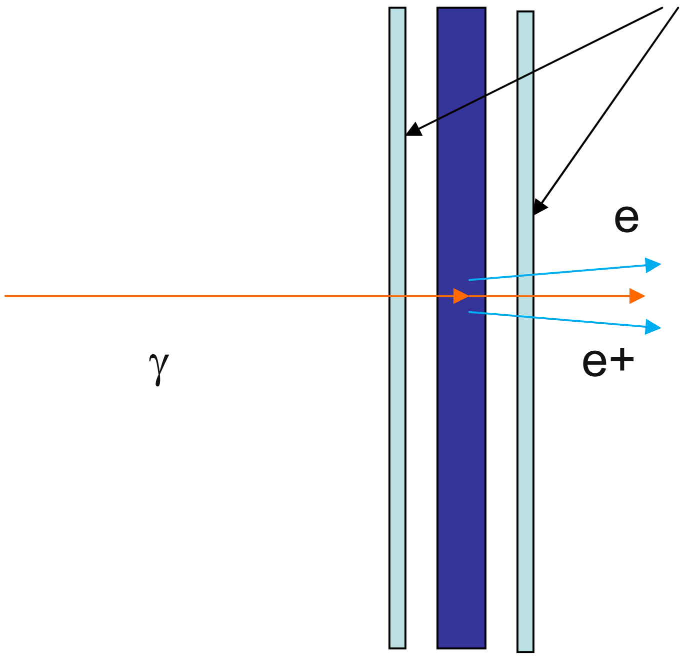
- We designed a prototype flux concentrator experiment and confirmed the accuracy of model.

- An flux concentrator based ILC AMD was designed using the equivalent circuit model. The designed AMD has a peak magnetic field at target exit equal to 5 Tesla. The peak power input to flux concentrator is about 5MW. The average power input to the entire AMD is around 200KW.

Thermal Dynamic Study on Target Chamber Window

As requested by our collaborators, we did this study to verify the feasibility of target chamber window.
Based on our simulations, due to the energy deposition, the downstream window is not feasible.

Target chamber window thermal dynamic calculation



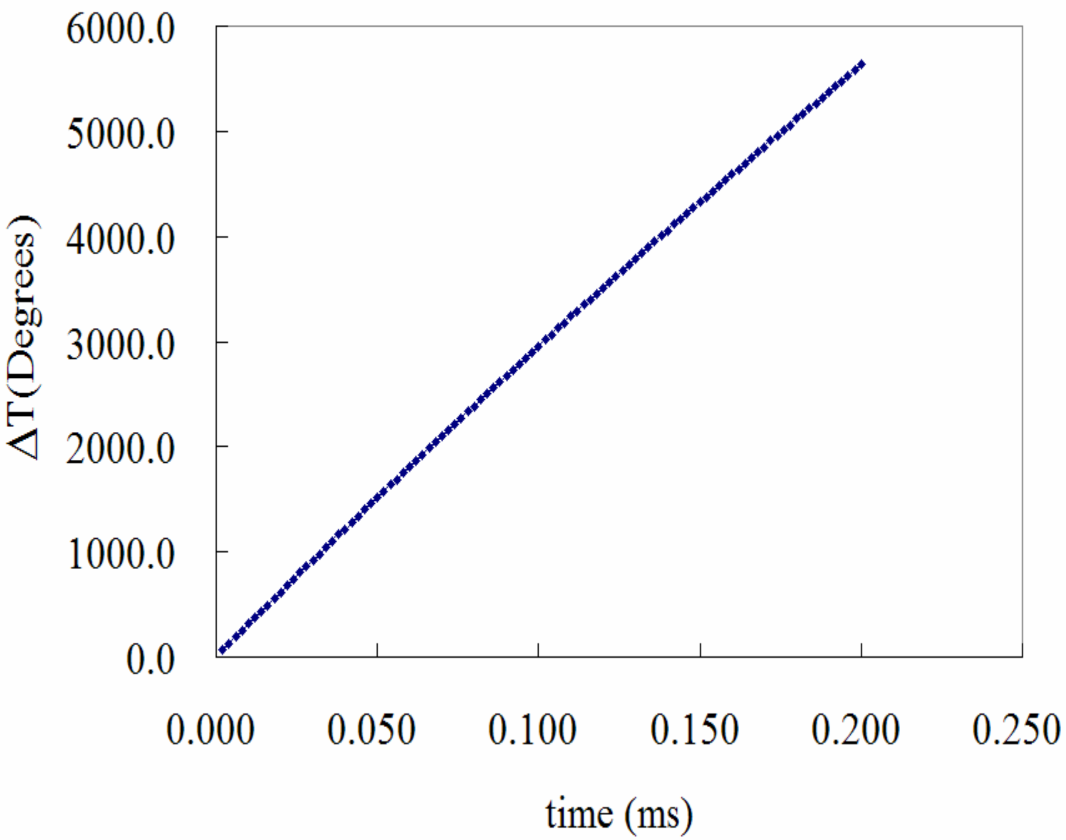
Beryllium window of 0.375mm thickness

e-,e + and γ

Undulator: K=1 λu=1cm, 100m long with 150GeV 3nC electron drive beam. The size of electron drive beam is σx=0.1mm and the bunch length is about 2.5ps. The drift to the target is 500m

- **~0.32mJ per bunch deposited in upstream window**
- **~8.4mJ per bunch deposited in downstream window**

Transient Thermal Response on downstream window.



2820 bunches with 2.5ps bunch length and 308ns bunch interval are used in transient calculation.

Since the energy deposited upstream is about 4% of the down stream, the temperature rise in upstream window will be up to ~1100 for the 1st bunch train of 2820 bunches. The time duration of one bunch train is about 0.87ms

The results presented here assumes that all lost energy in material will be transferred into heat

Energy Deposition Profile of Target

This work is done per the request of collaborators from LLNL.

Conditions and parameters

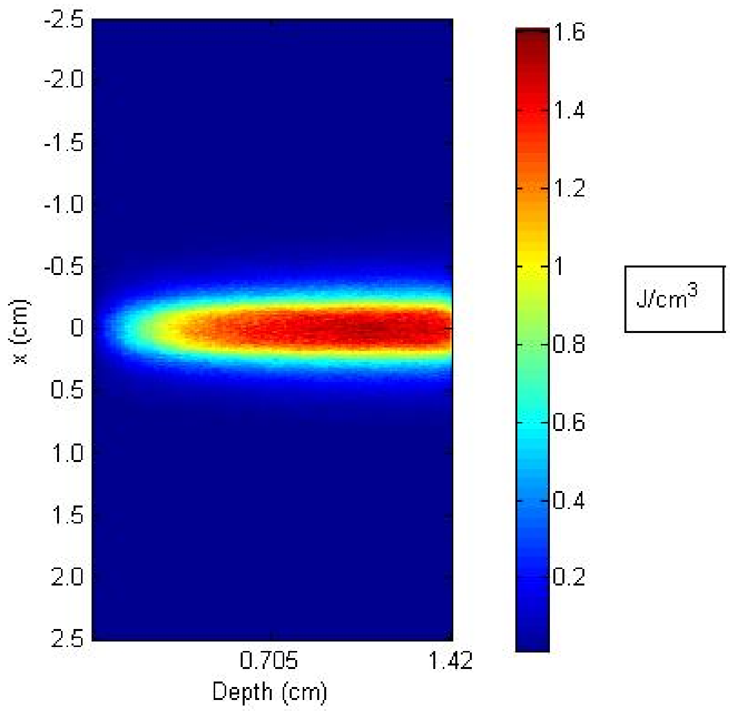
- Undulator parameters: K=0.92, λu=1.15cm
- Drive beam: 150GeV e-, 3nc per bunch
- Target: Ti, 0.4 radiation length.
- Length of Undulator: 100m
- Drift to target: 500m
- Photon collimation: None
- Photon beam axis: z

Configuration of Energy Deposition Numerical Monitor for Energy Deposition Profile

- Size of bin: dx*dy*dz=0.01cm*0.02cm*0.0102cm
- Dimension of bins: nx*ny*nz=500*1*140
- Aligned on XZ plane
- Code used: EGS4
- Energy cut: 0.01MeV for photon, 0.52MeV for e-/e+

Energy Deposition Profile and General Results

Energy deposition profile showing here is calculated per drive e- bunch



- Energy deposition in target per bunch is about 0.5255J
- Energy deposition per pulse: about 1482J
- Power deposition per pulse 1482(J)/0.874e-3(s) ~= 1.696MW
- Average power deposition: 1482*5=7.4KW

The data for this profile has been provided to LLNL for cooling and stress study.

Laser Compton Scheme
--Collaboration with KEK

Beside of doing undulator based positron source simulations, we are also doing simulations KEK/CLIC to help them on the Laser Compton Scheme positron source.